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(54) **Apparatus and method for a high contrast, wide angle, color, flat panel, liquid crystal display.**

(57) In order to provide a high contrast, wide angle, color, liquid crystal display, the pixel elements (61-66) have each subpixel color cell fabricated with a thickness (d) of liquid crystal material through which light is transmitted that is less than the liquid crystal thickness for minimizing optical transmission when the pixel cell is in an off-state. Using a thickness less than that for minimizing optical transmission on the axis perpendicular to the plane of the display panel (and component cells) results in the minimum optical transmission at an off-axis viewing angle. By permitting a small amount of optical transmission along the axis of the display (as a result of using a liquid crystal thickness less than the thickness required for minimizing undesired transmittance), a relatively small undesired transmittance of light for the liquid crystal cell can be achieved over wide viewing angle; This thickness of liquid crystal for each pixel color is combined with an arrangement of color component cells for each pixel that minimizes the perceptible display image spatial noise (Fig. 3).

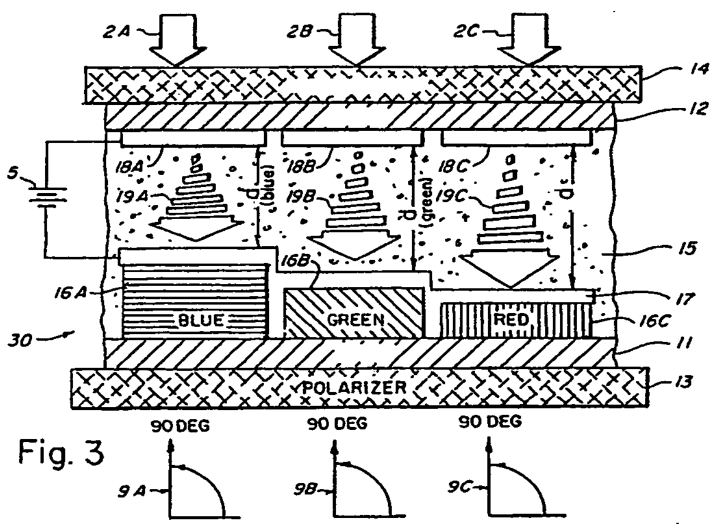


Fig. 3

APPARATUS AND METHOD FOR A HIGH CONTRAST, WIDE ANGLE, COLOR, FLAT PANEL, LIQUID CRYSTAL DISPLAY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to flat panel, color, liquid crystal displays and, more particularly, to liquid crystal displays having a wide viewing angle and with reduced image noise patterns.

2. Description of the Related Art

The use of liquid crystal color displays has proven attractive for many applications, such as avionic parameter displays used in an aircraft flight deck. The liquid crystal displays can be implemented in a flat panel configuration reducing the volume requirement resulting from the use of cathode ray displays.

However, the flat panel liquid crystal color displays of the prior art have had certain features that have compromised their acceptability. For example, the crossed polarizer, twisted nematic type of liquid crystal display has a transmission through the liquid crystal cell that is uninhibited for zero applied voltage. This liquid crystal display configuration is referred to as a normally white display and is used in many display applications such as in watches and calculators. In the present invention, the linear polarizers are oriented in a mutually parallel configuration, providing a display that normally provides no optical transmission when the liquid crystal is not activated and for which the optical transmission increases with applied voltage. Because of the properties of the liquid crystal material, undesired optical transmission can occur even in the liquid crystal cell off-state, as the result of the rotatory dispersion of polarized light introduced into the liquid crystal material.

Referring to Fig. 1, the effect of the rotatory dispersion on the transmission of light in a color, liquid crystal flat panel display is shown. Rotatory dispersion is a result of the optical rotation being a function of wavelength, λ . The flat panel display includes glass substrates 11 and 12 which enclose and contain the liquid crystal 15. A polarizer 14 is positioned on the exterior of substrate 12, while a polarizer 13 is positioned on substrate 11. On the interior surface of substrate 11 are positioned a multiplicity of color filters; blue filter 16A, green filter 16B, and red filter 16C are shown; and positioned over the interior surfaces of filters 16A through 16C is a transparent conducting electrode 17. The three filters permit the color of a single image pixel to be controlled. Positioned on an interior surface of substrate 12 are a plurality of transparent conducting electrodes 18A-18C, each conducting electrode proximate an associated filter (16A-16C). The electrodes 18A-18C can be individually addressed by a controllable voltage supply 5 using an addressing apparatus not shown. In the absence of a voltage applied between electrodes and when the liquid crystal material 15 is a twisted nematic material providing normally black display, then, as unpolarized light 2A-2C is applied to the display, the light is polarized by polarizer 14. The polarized light 19A-19C travels through the twisted nematic liquid crystal, the polarized light is rotated through an angle of approximately 90° and is absorbed by polarizer 13 (which is oriented parallel to polarizer 14). The rotatory dispersion of polarized light, resulting from the wavelength dependence of the birefringence of the liquid crystal material, will generally provide a rotation that is different from the desired 90° optical rotation by an amount that is a function of the wavelength of the radiation. Thus, not all the light is absorbed by polarizer 13 and the display has undesirable off-state transmission. As will be shown below, a thickness of liquid crystal material can be found for which the optical rotation of the transmitted (green) radiation will be essentially 90°, i.e., will include no undesired components as shown by graph 9B. However, the longer wavelength red radiation will, at this distance, have a rotation less than 90°, cf. graph 9c; while the shorter wavelength blue radiation will be rotated through an angle greater than 90°, cf. graph 9A.

In an article by C.H. Gooch et al entitled "The Optical Properties of Twisted Nematic Liquid Crystals with Twist Angles 90°" in J. Phys. D: Appl. Phys., vol 8, 1975, pp. 1575 to 1585; the transmission through a liquid crystal cell is given by

$$T(\lambda,d) \approx (\sin[\theta x(1+u^2)^{1/2}])^2/(1+u^2)$$

where:

u	$= u(\lambda,d) \approx \pi x d x \Delta n/\theta x \lambda$	
Δn	is the birefringence of the material	
θ	≈ 90 deg	
λ	= radiation wavelength, and	
d	= thickness of the liquid crystal.	

Referring to Fig. 2, a plot of the optical transmission $T(\lambda,d)$ is shown as a function of thickness, d, of the liquid crystal medium. As will be clear from Fig. 2, each wavelength reaches the minimum transmission value at different thicknesses of liquid crystal medium. Comparing the graphs 9A-9C of Fig. 1 with the plot of transmission versus thickness of liquid crystal demonstrates that, for a single thickness of liquid crystal material, undesired

radiation will always be transmitted by the cell, i.e., the first transmission minimum for the three colors is different. Therefore, the contrast ratio, the ratio of radiation transmitted in the transmitting mode of the cell versus the transmission of radiation in the nontransmitting mode of the cell will be reduced.

In U.S. Patent 4,632 ,514 by Ogawa et al, issued December 30, 1986, the contrast ratio for a twisted nematic liquid crystal flat panel display is improved by providing a thickness of the liquid crystal medium that is dependent on the filter through which the radiation passes. Referring to Fig. 3, the configuration of Fig. 1 is generally reproduced. However, the important difference is the blue radiation 19A, the green radiation 19B, and the red radiation 19C each travels through a different thickness of twisted nematic liquid crystal 15. The thickness d(blue) of liquid crystal material through which the blue radiation 19A travels, the thickness d(green) of liquid crystal through which the green radiation 19B travels, and the thickness d(red) of liquid crystal material through which the red radiation 19C is determined by the first minima of the optical transmission of Fig. 2. The result is that for each of the three component color radiation, the rotation of the polarized radiation resulting from the passage through the liquid crystal material is substantially 90° as shown in graphs 9A-9C.

The display described above provides a high contrast ratio for radiation viewed substantially perpendicular to the glass substrates, i.e., along the display axis. However, in many applications in which the use of liquid crystal displays would be most advantageous, the display must be viewed from an off-axis position.

Referring now to Fig. 4, an demonstration is provided illustrating why the contrast ratio is not maintained when the transmitted radiation is viewed off-axis. Impinging radiation 41 of a given color, when viewed on-axis by observer 45A, is rotated substantially 90° (cf. graph 49A) by the transmission through a distance d_1 of the liquid crystal material. However, when the observer 45B is viewing the radiation off-axis, the distance travelled by the radiation is $d_2 \approx d_1/\cos\theta$, resulting in a rotation of the radiation in excess of 90°, thereby resulting in a deterioration of the contrast ratio. The contrast ratio deterioration will increase with increasing viewing angle.

A need has therefore been felt for a liquid crystal display in which a high contrast ratio can be achieved for a large range of off-axis viewing angles. In addition, a technique has been needed to reduce the image spatial noise in a liquid crystal display that will reduce the highly perceptible periodic spatial patterns.

It is an object of the present invention to provide an improved flat panel liquid crystal display. In particular the display should have reduced undesired, dark state optical transmission over a wide viewing angle. These and other objects are achieved by the invention as characterized in the independent claims. Preferred details and embodiments of the invention are described in the dependent claims.

The present invention selects a particular thickness of liquid crystal material through which a color component must pass to improve the uniformity of image as a function of viewing angle.

It is still another feature of the present invention to provide a thickness of twisted nematic liquid crystal through which monochromatic radiation must pass which is less than the smallest thickness minimizing the transmission of the radiation with no electric field applied to the liquid crystal.

It is a still further feature of the present invention to provide a flat panel liquid crystal display in which the component color dots of each pixel have a triangular or delta configuration.

SUMMARY OF THE INVENTION

The aforementioned and other features are accomplished, according to the present invention, by providing; in a twisted nematic, flat panel liquid crystal display; a thickness of liquid crystal material, through which each radiation color component must pass, meeting predetermined requirements. In particular, each radiation color component must pass through a thickness of liquid crystal material that is less than the thickness for providing the smallest distance for which substantially no light is transmitted when the twisted nematic liquid crystal material is not subjected to an electric field. The thickness of the region of transmission can be selected for each radiation color component to provide an improved contrast ratio at an off-axis viewing angle. This configuration provides a generally symmetrical broadening of the luminance with viewing angle, making the display viewable at increased off-axis angles. The color dots of each pixel are arranged in a triangular configuration to minimize the observability of certain types of spatial noise patterns.

These and other features of the invention will be understood upon reading of the following description along with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of a portion of a flat panel, liquid crystal, color, display.

Figure 2 is a plot of optical transmission light through a twisted nematic, liquid crystal as a function of thickness of the liquid crystal for a plurality

of wavelengths.

Figure 3 is a cross-sectional view of the flat panel liquid crystal display of Figure 1 wherein the axial contrast ratio has been improved.

Figure 4 illustrates the reason for the deterioration of the contrast ratio for off-axis viewing of transmitted radiation through a liquid crystal medium.

Figure 5 illustrates the angular dependence of the off-state optical transmission on the thickness of the liquid crystal material for several thicknesses thinner than the minimum thickness.

Figure 6 illustrates the arrangement for color components of a pixel according to the present invention.

Figure 7 illustrates the relationship between the (horizontal) viewing angle and the luminance of a liquid crystal display when the display is in an off-state mode, the display having the delta arrangement of color dots and wherein the thickness of the liquid crystal medium is less than the distance to minimize the on-axis radiation resulting from rotatory dispersion.

Figure 8 illustrates the angular dependence of the luminance for the liquid crystal display of the present invention as a function of grayscale level for transmitted radiation.

Figure 9 illustrates the angular dependence of of the contrast ratio as a function of angle for several grayscale levels.

DESCRIPTION OF THE PREFERRED EMBODIMENT

1. Detailed Description of the Figures

Referring next to Fig. 5, the angular dependence of the transmission of radiation as the thickness of the liquid crystal medium is reduced from the value which produces the highest contrast ratio for on-axis transmission of light. As the thickness of the liquid crystal medium decreases, the zero transmission angle changes from the on-axis orientation to an increasingly large viewing angle. As the thickness of the liquid crystal medium is decreased for the first of the transmission minima, an increasing amount of light is transmitted on-axis, i.e., with a 0° viewing angle.

Referring next to Fig. 6, the arrangement of color components of an image pixel according to the present invention is shown. This arrangement, hereinafter referred to as the delta arrangement or configuration, provides for a plurality of rows of dots, each dot providing a complementary color. The arrangement of the color dots is replicated in a row with a periodicity of three. An adjacent row has the same periodicity, but the color dots are shifted by one and one half color dot positions with respect of the adjacent row. An image pixel 61 is composed of two complementary color dots 61A and 61B from a row and a third complementary color dot 61C from an adjacent row. This arrangement disrupts the patterns produced by certain types of images and, consequently, the patterns become less discernable to an observer.

Referring next to Fig. 7, the luminance for a twisted nematic liquid crystal in the off-state is shown. The display has the delta arrangement of color dots for each pixel. The thickness of liquid crystal medium through which each radiation color component passes is less than the thickness for first radiation color component minimum (cf. Fig. 2). The luminance has a local maximum at the on-axis (0°) viewing angle, goes through a relatively symmetric local minimum (at approximately 20°), and increases rapidly thereafter. An extended local region of relatively low off-state-luminance is provided over a relatively large angle.

Referring next to Fig. 8, the white radiation for a multiplicity of grayscale levels as a function of (horizontal) viewing angle is shown. The display uses a twisted nematic liquid crystal with the thickness of the liquid crystal, through which each radiation color component travels, that is less than the first minimum derived from minimizing the radiation color component optical dispersion (i.e., the first minimum of Fig. 2 for the radiation color component). For the highest grayscale levels, the radiation has a distinct maximum for the on-axis viewing angle (0°), a result of the substantially completely oriented liquid crystal molecules. Where the liquid crystal molecules are less than completely oriented at lower grayscale levels, relatively uniform luminance is observed over a wide viewing angle.

Referring to Fig. 9, the angular dependence of the contrast ratio for several grayscale levels are shown. Once again, the display is a flat panel, color, liquid crystal display in which the liquid crystal material is a twisted nematic liquid crystal. The thickness of liquid crystal material is less than the thickness providing the first minimum for optical transmission of the radiation color component (i.e., the first minimum of Fig. 2 for the radiation color component). The contrast ratio has a generally symmetric off-axis maxima and has a local minimum generally on-axis (0°). On either side of the maxima, the contrast ratio falls off rapidly with increasing viewing angle.

2. Operation of the Preferred Embodiment

The liquid crystal display of the present invention provides a display with a relatively large off-axis viewing angle. The improved viewing angle characteristic is accomplished by determining the

first minimum thickness for transmission of monochromatic light through the 90° twisted nematic liquid crystal. The undesired radiation color component resulting for rotatory dispersion is minimized for a normally black twisted nematic liquid crystal display cell having the first minimum thickness. After this thickness has been determined, then the thickness of liquid crystal material through which the monochromatic light must pass is reduced, providing a minimum off-state transmission at an off-axis viewing angle. This display configuration results in a more uniform transmission of radiation as a function of viewing angle, particularly at lower grayscale levels. In addition to the uniformity over a greater angle, the configuration of the present invention results in greater symmetry for the radiation viewed off-axis.

The present invention further envisions that the pixels of the display will be implemented by color dots or subpixels that are arranged in a triangular or delta array. This array disrupts certain spatially oriented image noise and results in the noise patterns being more difficult to observe.

Claims

1. A flat panel liquid crystal display for displaying color images, said display comprising:
   a) a multiplicity of pixels (61-66); each pixel having,
   b) a region (15) containing said liquid crystal, a pair of electrodes (17, 18) bounding said region of liquid crystal, said electrodes and said region of liquid crystal material being in a radiation path,
   c) a first (14) and a second (13) polarizer in said radiation path, said first and said second polarizers being external to said pair of electrodes, and
   d) a filter (16) in said radiation path, said filter determining a color produced by said radiation path for said display;
   characterized in that
   e) each pixel (61-66) includes a plurality of subpixels (61A, B, C - 66A, B, C); and
   f) a distance (d) between said electrodes (17, 18) is less than a minimum distance to minimize the off-state transmission through said liquid crystal (15) of radiation having said color, said radiation being generally parallel to said radiation path.

2. The display of Claim 1, **characterized in that**
   a) each pixel (61) includes three subpixels (61A - 61C);
   b) each subpixel has a different filter (16A - 16C) associated therewith, and
   c) said three subpixels are positioned in a generally triangular arrangement.

3. The display of Claim 1 or 2, **characterized in that** said plurality of subpixels (61A - 66C) includes subpixels (61A - 66A) for providing a red color, subpixels (61B - 66B) for providing a green color, and subpixels (61C - 66C) for providing a blue color.

4. The display of one of the preceding claims, **characterized in that** said polarizers (14, 13) are oriented in mutually parallel directions, a subpixel without a voltage applied thereto being in an off-state.

5. The display of one of the preceding claims, **characterized in that** the thickness (d) of a liquid crystal subpixel cell has a minimum transmission for an off-state of said liquid crystal cell at a viewing angle of approximately 20°.

6. The display of one of the preceding claims, **characterized by** activation means for applying a controllable voltage to each subpixel.

7. A flat panel, liquid crystal display for displaying color images, **characterized by:**
   a) a group of first subpixels (61A - 66A), each of said first subpixels having a first filter (16C) for transmitting radiation of a first color (red) through said first subpixels, said first subpixels having a first thickness (d-(red)) of liquid crystal through which said first color radiation is transmitted, said first thickness being less than a thickness for providing minimum first color radiation transmission for a subpixel off-state at zero viewing angle;
   b) a group of second subpixels (61B - 66B), each of said second subpixels having a second filter (16B) for transmitting radiation of a second color (green) through said second subpixels;
   c) a group of third subpixels (61C - 66C), each of said third subpixels having a third filter (16A) for transmitting radiation of a third color (blue) through said third subpixel; and
   d) voltage control means coupled to said first, second, and third subpixels for controlling an intensity of optical transmission through each subpixel.

8. The display of Claim 7, **characterized in that** said first thickness (d(red)) provides a minimum transmission of said first color radiation for a subpixel off-state at a preselected viewing

angle.

9. The display of Claim 7 or 8, **characterized in that** said second subpixels (61B - 66B) have a second thickness (d(green)) of liquid crystal through which said second color (green) radiation is transmitted, said second thickness being less than a thickness for providing minimum first color radiation transmission for a subpixel off-state at zero viewing angle.

10. The display of one of the preceding claims, **characterized in that** each pixel (61 - 66) of said display includes a first subpixel (61A), a second subpixel (61B), and a third subpixel (61C); said first, said second, and said third subpixels being positioned in a triangular arrangement of said pixel.

11. The display of claim 10, **characterized in that:**

a) different color subpixels (61A red, 61B green, 62C blue) are arranged in a first row including a periodic sequence of those subpixels; and

b) a second row including a corresponding sequence of subpixels (61C blue, 65A red, 65B green) is located in front of said first row but is offset with respect to the first row such that the subpixels of the second row are located in front of the gap between adjacent subpixels of the first row.

12. The display of one of the preceding claims, **characterized in that** said liquid crystal is a twisted nematic liquid crystal.

13. The display of one of the preceding claims, **characterized in that** said subpixels (61A - 66C) include polarizers (14, 13) having a parallel orientation therebetween, an off-state of a subpixel occurring when a voltage is not applied to said subpixel.

14. A method of providing a color liquid crystal display comprising the steps of:

a) providing said display with a multiplicity of pixels (61 - 66), each pixel related to a display image point;

b) dividing each pixel of said liquid crystal display into a plurality of subpixels (61A - 66C), each subpixel of a liquid crystal display pixel transmitting a preselected color radiation;

c) selecting a first distance (d) for optical transmission of radiation through a liquid crystal material of each preselected color radiation subpixel less than a distance for minimum optical transmission of said subpixel in an off-state, said minimum transmission being determined at zero viewing angle; and

d) controlling an intensity of light transmitted through each subpixel by controlling a voltage applied to said each subpixel.

15. The method of Claim 14, **characterized in that** said selecting step further includes the step of selecting a distance (d) having a minimum optical transmission at a preselected viewing angle for said off-state.

16. The method of Claim 14 or 15, **characterized in that** said dividing step includes the step of selecting a first subpixel (61A) for transmitting a red color radiation, selecting a second subpixel (61B) for transmitting green color radiation, and selecting third subpixel (61C) for transmitting blue color radiation.

17. The method of one of the claims 14 to 15, **characterized by** the step of arranging said color radiation subpixels in a triangle.

18. The method of one of the claims 14 to 17, **characterized by** the step of arranging polarizers (14, 13) of said liquid crystal display wherein said an off-state for each subpixel results when an activation voltage is not applied thereto.

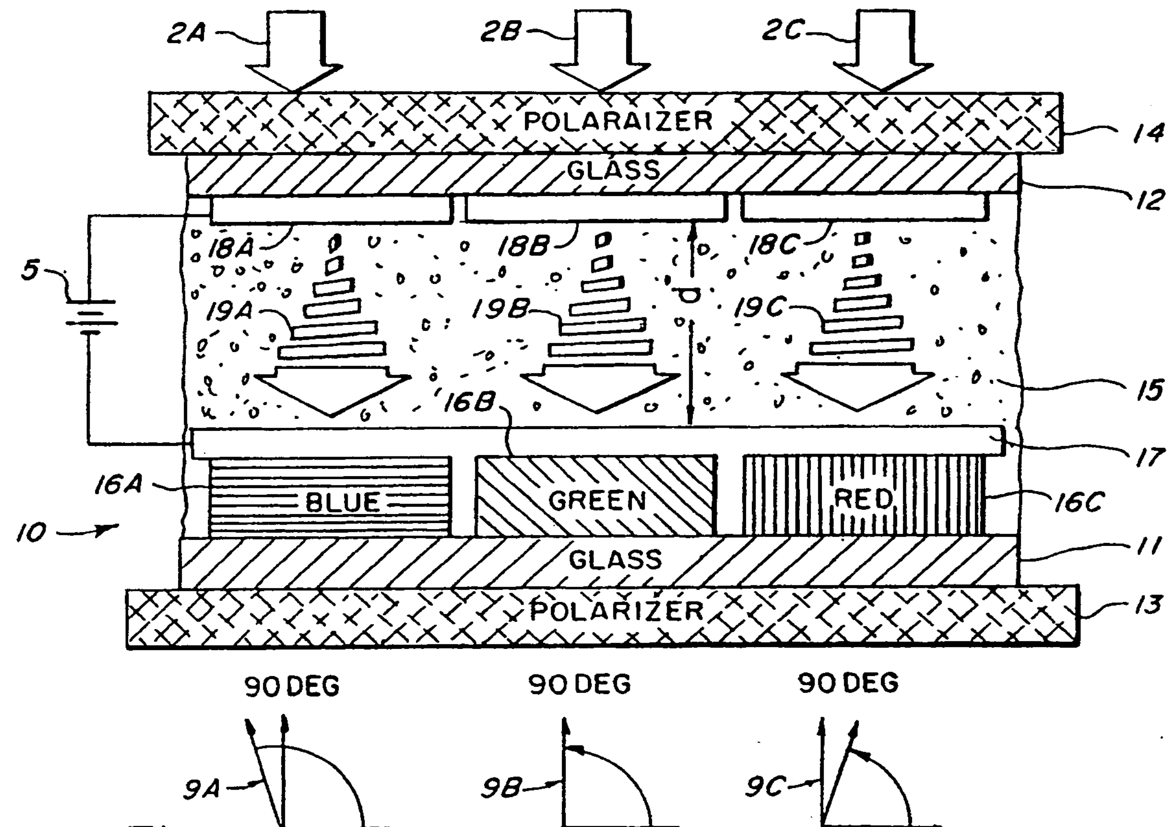

2A
2B
2C
POLARAIZER
14
GLASS
12
18A
18B
18C
5
19A
19B
19C
15
16B
17
16A
BLUE
GREEN
RED
16C
10
GLASS
11
POLARIZER
13
90 DEG
90 DEG
90 DEG
9A
9B
9C

Fig. I

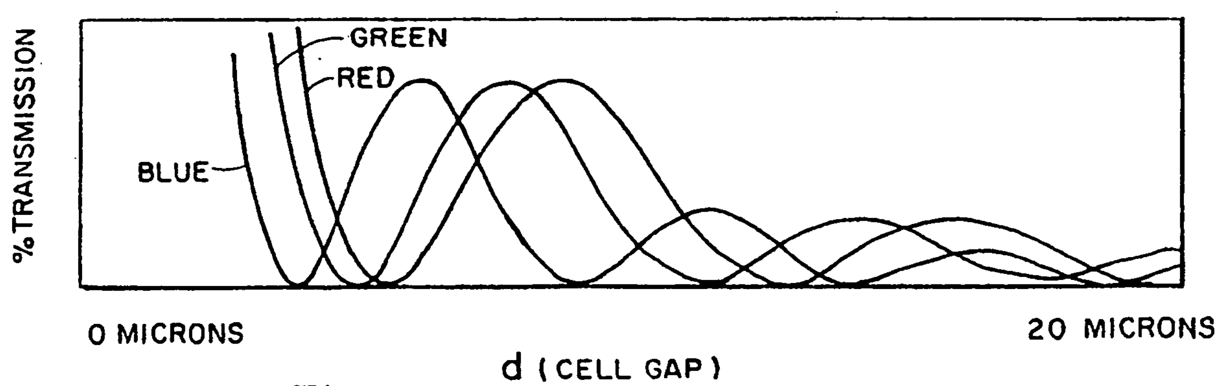
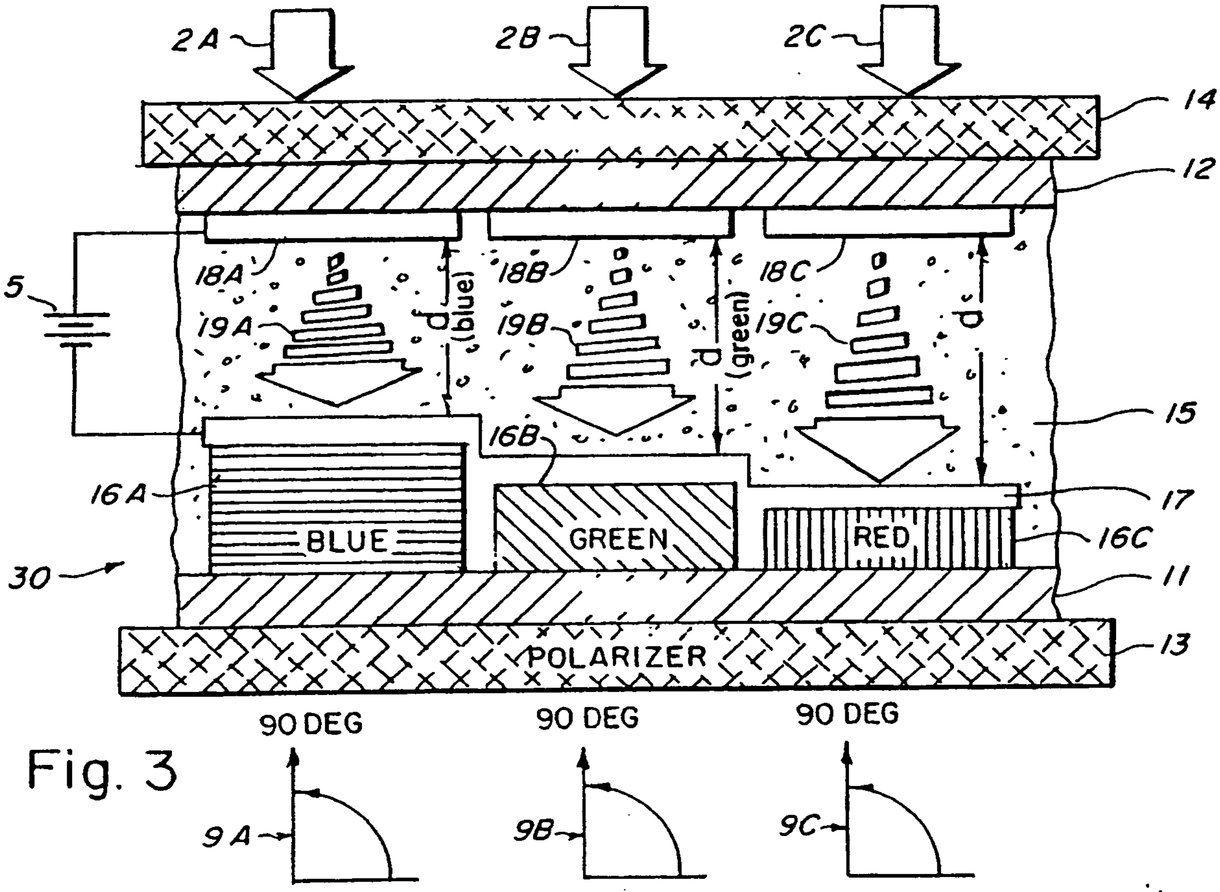

GREEN
RED
BLUE
% TRANSMISSION
0 MICRONS
20 MICRONS
d (CELL GAP)

Fig.2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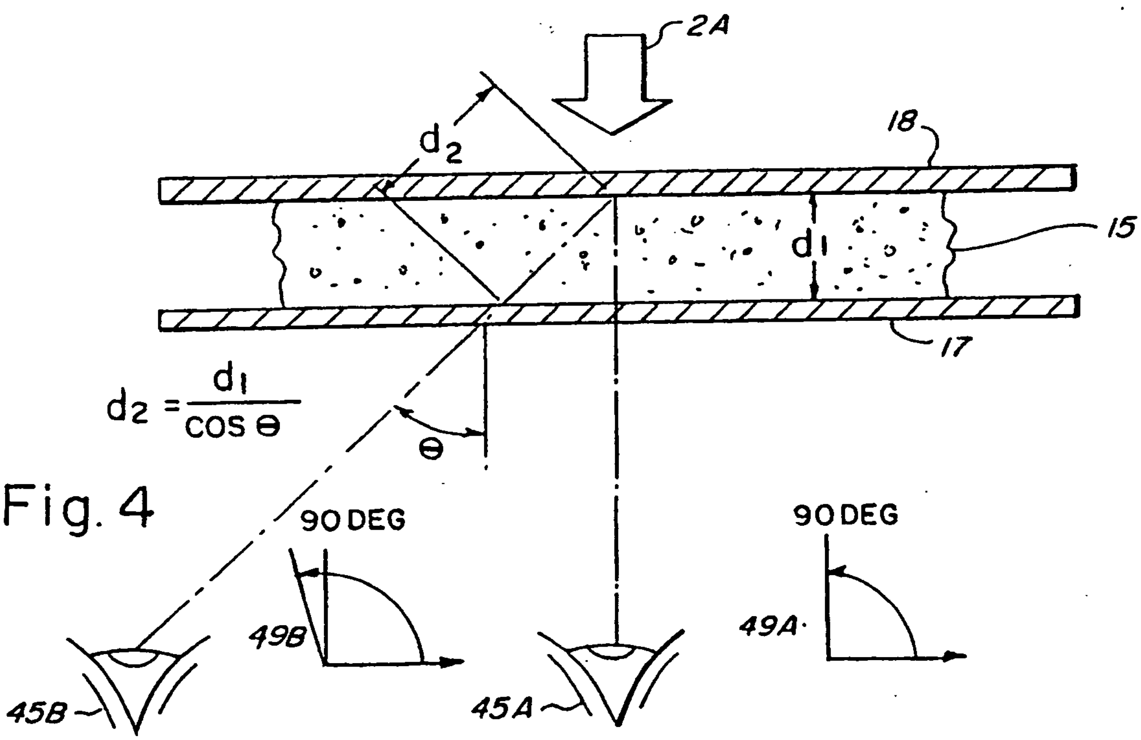
2B
2C
14
12
5
18A
18B
18C
19A
19B
19C
d (blue)
d (green)
d
15
16B
16A
17
BLUE
GREEN
RED
16C
30
11
POLARIZER
13
90 DEG
90 DEG
90 DEG
9A
9B
9C

Fig. 3


2A
d_2
18
15
d_1
17
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θ
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90 DEG
49B
49A
45B
45A

Fig. 4

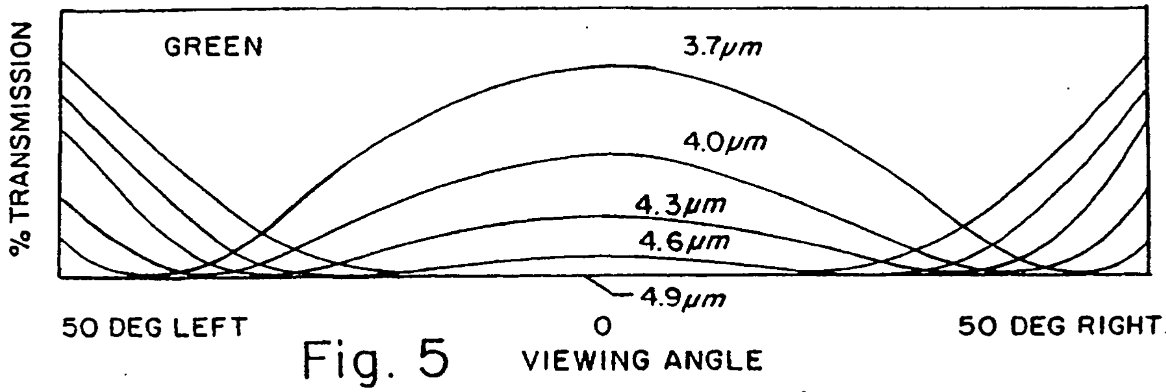


Fig. 5

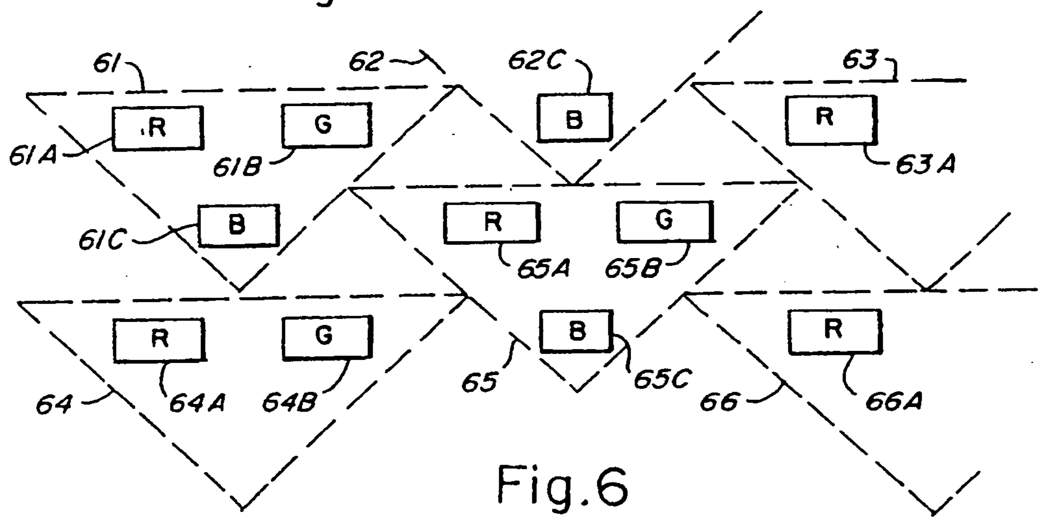


Fig.6

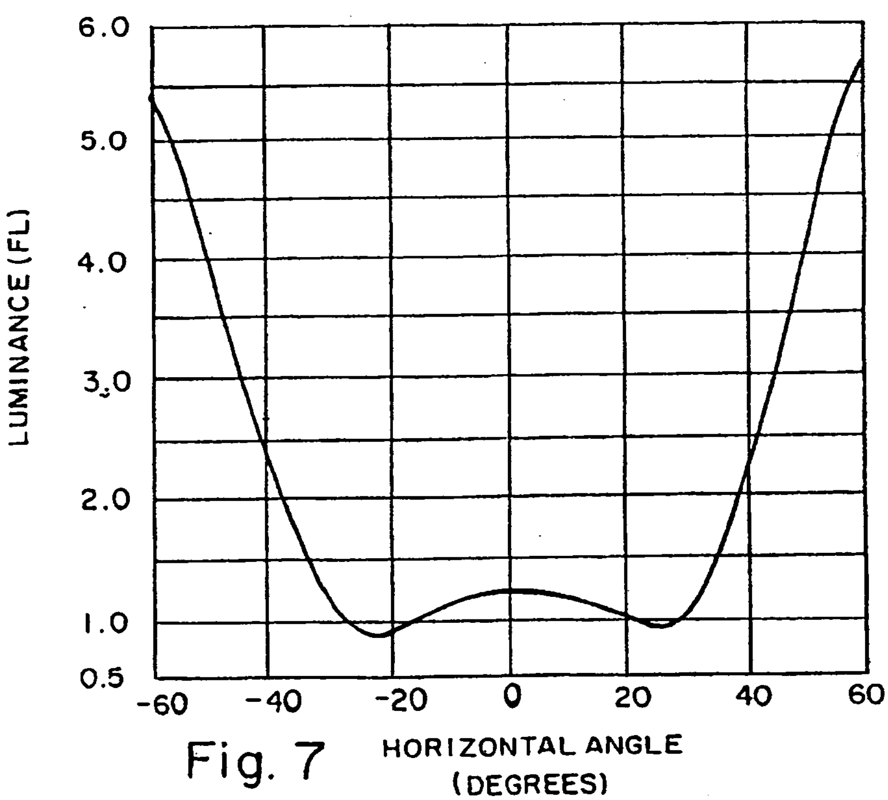
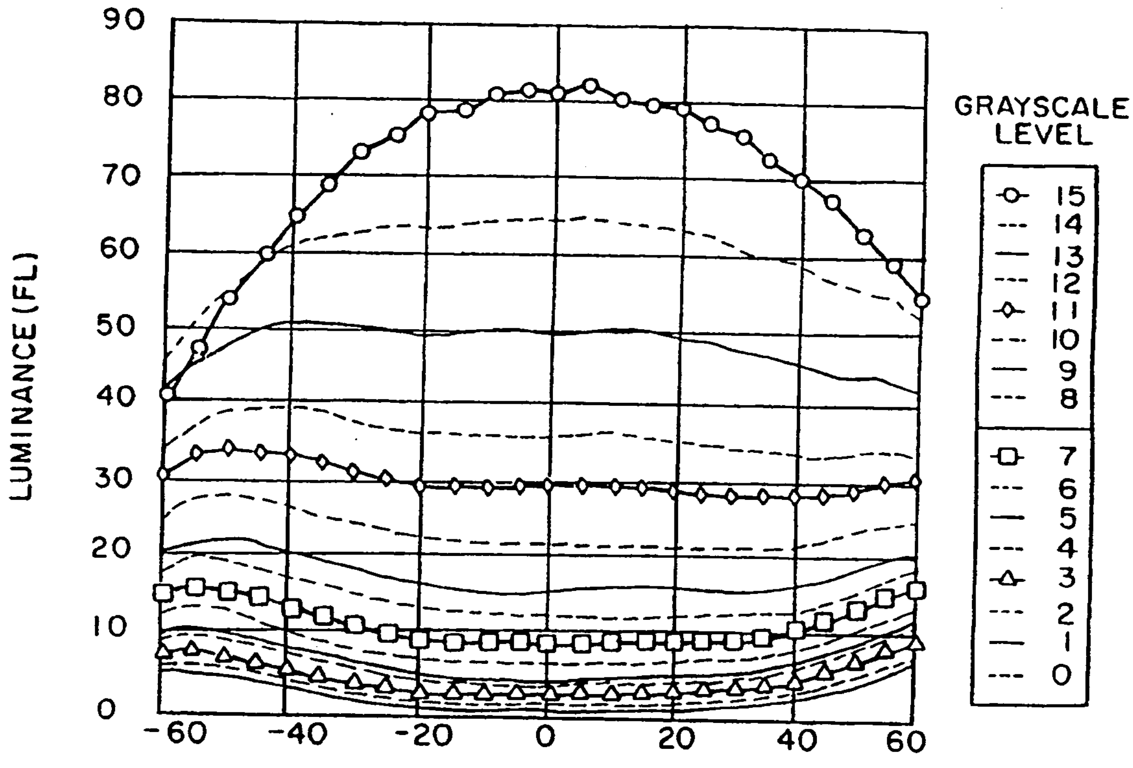


Fig. 7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HORIZONTAL ANGLE (DEGREES)
GRAYSCALE LEVEL
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14
13
12
11
10
9
8
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6
5
4
3
2
1
0

Fig. 8

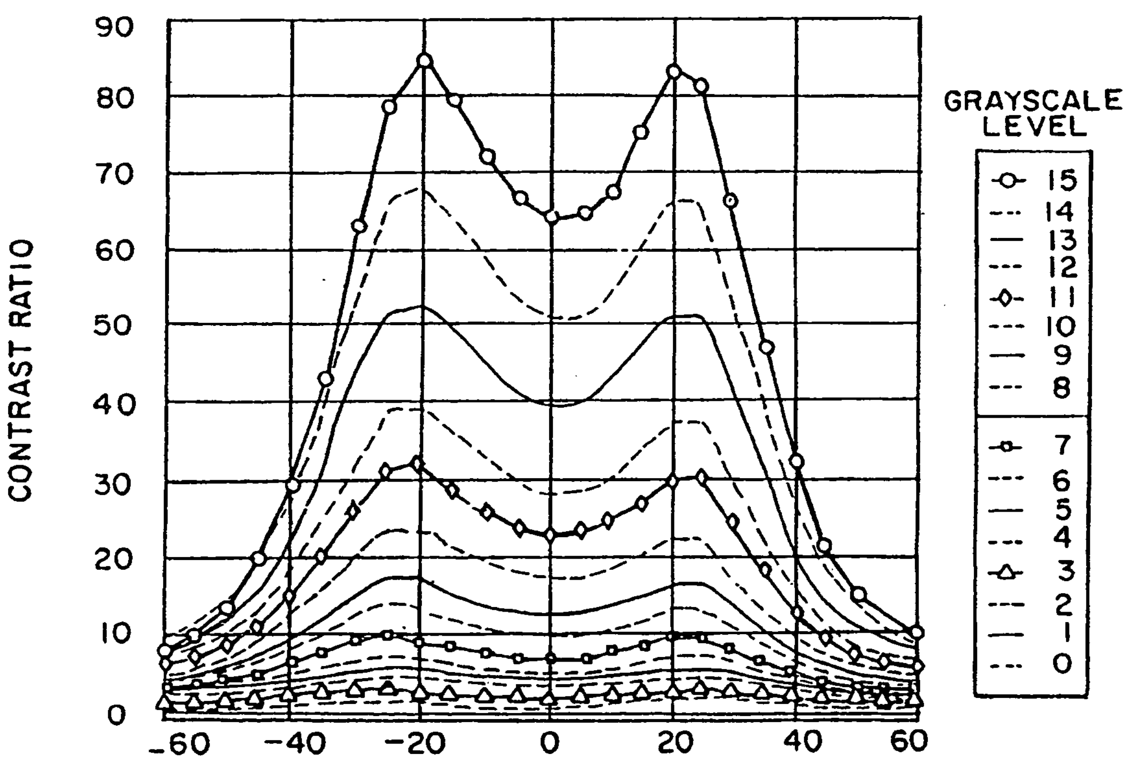
CONTRAST RATIO
HORIZONTAL ANGLE (DEGREES)
GRAYSCALE LEVEL
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

Fig. 9

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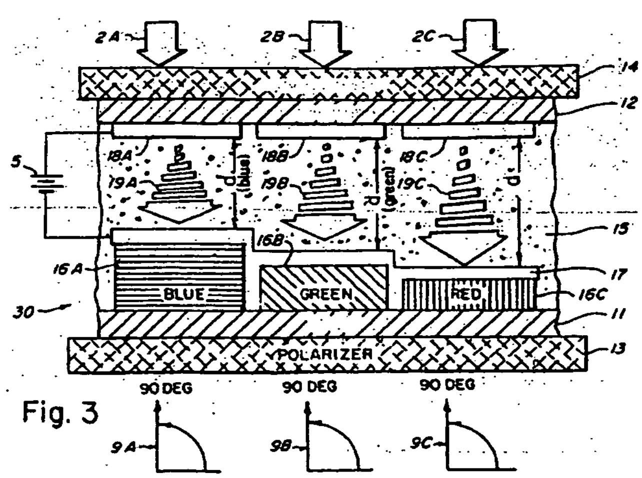

Fig. 3

EP 0 433 931 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 12 4320

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,A	EP-A-0 152 827 (MATSUSHITA ELECTRIC) * Page 3, line 12 - page 5, line 2; page 6, line 3 - page 8, line 2; page 14, lines 2-12; page 19, line 12 - page 21, line 7; page 29, lines 2-18; figures 1,18,21,23 *	1-4,6,7, 12-14,16, 18	G 02 F 1/1335
A	GB-A-2 078 389 (MERCK) * Page 1, line 40 - page 2, line 8; page 5, lines 11-27; figures 1,4,5 *	1,5,7-9, 12,14,15	
A	PATENT ABSTRACTS OF JAPAN, vol. 9, no. 13 (P-328)[1736], 19th January 1985; & JP-A-59 159 127 (MATSUSHITA) 08-09-1984 * Figure 3 *	1,7,9,14	
A	PATENT ABSTRACTS OF JAPAN, vol. 6, no. 175 (P-141)[1053], 9th September 1982; & JP-A-57 90 618 (HITACHI SEISAKUSHO) 05-06-1982 * Whole document *	1,7,9,14	
A	EP-A-0 189 214 (NEC) * Page 19, lines 1-8; page 31, line 25 - page 36, line 2; figures 4B,6B,9A,9B *	2,3,10,11, 17	**TECHNICAL FIELDS SEARCHED (Int. Cl.5)** G 02 F

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	16 October 91	STANG I.

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